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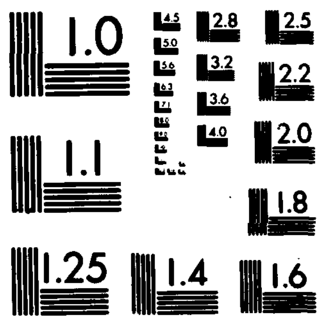
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RESEARCH AND DEVELOPMENT TECHNICAL REPORT
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MANUFACTURING METHODS AND TECHNOLOGY PROGRAM FOR RUGGEDIZED TACTICAL FIBER OPTIC CABLE

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FOURTH QUARTERLY PROGRESS REPORT
FOR PERIOD
APRIL 1, 1980 - JUNE 30, 1980

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CORADCOM
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FORT MONMOUTH, NEW JERSEY 07703

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MANUFACTURING METHODS AND TECHNOLOGY

PROGRAM FOR RUGGEDIZED TACTICAL

FIBER OPTIC CABLE

FOURTH QUARTERLY PROGRESS REPORT

FOR THE PERIOD OF
APRIL 1980 - JUNE 1980
Contract No DAAK80-79-C-0789

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report covers ~~the fourth quarter, April through June 1980, of the~~ Manufacturing Methods and Technology Program for Ruggedized Tactical Fiber Optic Cable. The scope of this quarter's effort, as reported herein, includes the following tasks and achievements:

Cable Process Optimization,

a. Complete final optimized engineering samples;

b. Begin fiber fabrication for confirmatory sample phase;

c. Deliver third engineering sample and test report (final optimized engineering samples).

2. Use of Facilities:

a. Achieve 100% of production rate on the high speed strander;

b. Achieve 75% of production rate on the Kevlar® serving line;

c. Achieve 100% of production rate on the extrusion lines;

d. Achieve 100% of production rate on the fiber spooling line;

e. Characterize test stations and run time studies;

3. Secondary Performance Milestones;

a. Achieve 0.35 dB/km induced attenuation from cabling operation;

b. Achieve 50% cable yield.

In addition to reporting progress on these milestones the report covers any revisions or improvements in process, equipment, tooling manufacturing flow, and specifications. Any changes in key personnel on the program are identified. The program milestones for the next quarter are listed.

MANUFACTURING METHODS AND TECHNOLOGY PROGRAM

FOR RUGGEDIZED TACTICAL FIBER OPTIC CABLE

FOURTH QUARTERLY PROGRESS REPORT

For the Period of April 1980 - June 1980

Object of Study:

To Establish an Automated Production Process for Ruggedized Tactical Fiber Optic Cable

Contract No DAAK80-79-C-0789

Prepared by:

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ABSTRACT

This report covers the fourth quarter, April 1980 through June 1980, of the Manufacturing Methods and Technology Program for Ruggedized Tactical Fiber Optic Cable. The scope of this quarter's effort, as reported herein, includes the following tasks and achievements:

1. Cable process optimization
   a. Complete final optimized engineering samples
   b. Begin fiber fabrication for confirmatory sample phase
   c. Deliver third engineering sample and test report (final optimized engineering samples)
2. Use of Facilities
   a. Achieve 100% of production rate on the high speed strander
   b. Achieve 75% of production rate on the Kevlar® serving line
   c. Achieve 100% of production rate on the extrusion lines
   d. Achieve 100% of production rate on the fiber spooling line
   e. Characterize test stations and run time studies

3. Secondary performance milestones

   a. Achieve 0.35 dB/km induced attenuation from cabling operation

   b. Achieve 50% cable yield

In addition to reporting progress on these milestones the report covers any revisions or improvements in process, equipment, tooling manufacturing flow and specifications. Any changes in key personnel on the program are identified. The program milestones for the next quarter are listed.

PURPOSE

The purpose of this Manufacturing Methods and Technology (MM&T) Program is to establish automated production processes for Ruggedized Tactical Fiber Optic Cables in accordance with Specification MMT-789898 dated 2 February 1978, and ECIPPR No 15.

GLOSSARY

Fused Coupler	- Optical coupler for power splitting formed by fusing two or more optical fibers
Injection Fiber	- Illuminated fiber used as a measurement light source
ITT EOPD	- ITT Electro-Optical Products Division
Lock-In Amplifier	- Amplifier used for precise instrumentation measurements in which offset drift is compensated by using a chopped source signal as a reference
NA	- Numerical aperture
PCS Fiber	- Plastic clad silica fiber
RTV	- Silicone buffer coating (room temperature vulcanizing)
PIXEL	- Picture element

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1.0 NARRATIVE AND DATA

The following information covers a physical description of the device (Appendix A), performance, effects of processes, and measurement techniques used on this program.

1.1 Device

The following paragraphs define the methods used to fabricate the optimized rugged tactical fiber optic cable, manufacturing processes, and measurement techniques.

1.1.1 Ruggedized Cable Design

The purpose of this program is to establish an automated production process for a ruggedized tactical fiber optic cable. Figure 1 shows the general cable configuration that was optimized on the program.

1.1.2 Final Optimized Engineering Samples

Three cable samples (1 km length) were fabricated with 1.02 mm diameter buffered fibers, 7.6 cm lay length, and Roylar® E-9B polyurethane. These samples were evaluated with excellent results, except for low temperature attenuation increases and jacket splitting at low temperature (-54°C) during the mechanical

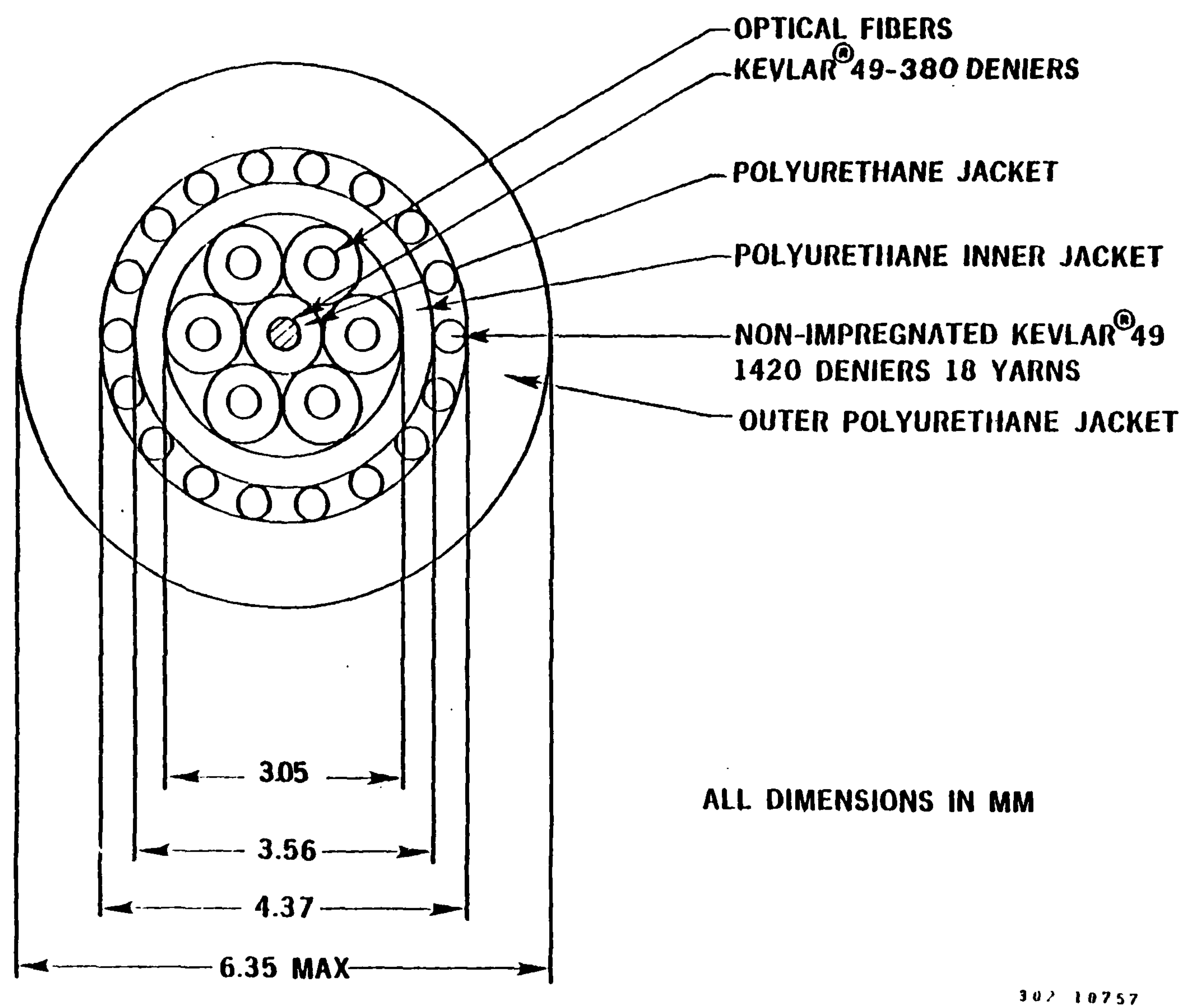

Figure 1. Basic MM&T Cable Design.

testing. The low temperature (-55°C) attenuation increase was caused by the buffered fiber diameter. When the Hytrel® 7246 buffer diameter is increased beyond 1.0 mm, the contraction of the material at -55°C exerts enough force to buckle the glass fiber causing high attenuation increase. The jacket splitting during the low temperature (-54°C) mechanical testing was caused by a poor batch of polyurethane from the supplier.

To verify that the cable was optimized, three 1 km cable samples were fabricated with 0.94 mm diameter buffered fibers, 7.6 cm lay length, and Roylar® E-9B polyurethane. These samples were evaluated for attenuation change at -55°C with results showing only a minor attenuation improvement over the 1.02 mm buffered fibers. These fibers were evaluated at low temperature prior to cabling with excellent results. Therefore, an interaction between the fiber and cable was taking place. The modulus of Roylar® E-9B polyurethane becomes very high at these low temperatures and was the most likely cause of inducing fiber stress.

An additional two cables 250 meters long were fabricated with 0.89 mm diameter fibers, 5.1, and 7.6 cm lay lengths, and

Roylar® E-80 polyurethane. This polyurethane was selected because it retains much lower modulus at -55°C and was evaluated fully at the start of this program. These samples had excellent low temperature attenuation, indicating that Roylar® E-9B does induce high fiber stress.

1.1.3 Manufacturing Problems

All cable samples were fabricated without any manufacturing difficulty and only minor variation in extrusion temperature is required when changing from Roylar® E-9B to E-80 polyurethane.

1.1.4 Conclusions and Recommendations

Detailed data from the Final Optimized Engineering Samples is contained in the third engineering sample test report. Based on the data collected from the cable optimization phases, the following recommendations are made for the cable design in the confirmatory sample phase:

a. Center filler element - The impregnated 380 denier Kevlar® 49 shall be extruded with Roylar® E-80 polyurethane to 0.94 mm ±0.05 mm (0.037" ±0.002"). Roylar® E-80 was selected because of its low temperature flexibility and fiber impact cushioning.

b. Optical fibers - The optical fibers shall be extruded to 0.89 mm ±0.05 mm (0.035" ±0.002"), with Hytrel® 7246. This diameter was selected because of its high impact strength while still retaining an excellent low temperature attenuation characteristic.

c. Fiber lay length - The optical fibers shall be helically applied with a 7.6-cm (3.0") lay length. This lay length provides maximum manufacturing rates and maintains the program requirements.

d. Inner jacket - Polyurethane E-80 shall be used for the inner jacket because of its best mechanical, low temperature flexibility and manufacturing performance.

e. Kevlar® strength member - The strength member shall consist of 18 strands of Kevlar® 49 (1428 denier) applied helically with a 10.2-cm (4.0") lay length to provide maximum fiber protection.

f. Outer jacket - The outer jacket shall be extruded to 6.18 mm ±0.17 mm with polyurethane E-80.

1.2 Process, Equipment, and Tooling

This section covers the manufacturing process, equipment used, and any necessary tooling.

1.2.1 Cable Manufacturing Process

This section describes each manufacturing station and its capabilities.

1.2.1.1 Fiber Rewind Station

This station (Figure 2, Operation E1) will be used to respool and inspect fibers in preparation for the subsequent stranding operation. The equipment consists of a rewinder, an optical lump detector to examine the fiber buffer jacket for any nonuniformities, and a constant-tension compensating payoff to eliminate any fiber breaks due to high tension levels.

This unit will allow fibers to be inspected for buffer jacket flaws optically at control tensions.

This station is operational except for the CTC constant-tension payoff assembly which shall be returned from the factory shortly. The unit required replacement of components and a complete factory adjustment.

1.2.1.2 Fiber Continuity Check Station

Before the fibers are stranded into a cable bundle it is essential that each fiber's continuity be tested and any broken fibers removed to ensure a high production yield. The unit used at this station (Figure 2, Operation E2) will include a large area light-emitting diode (LED) and a large

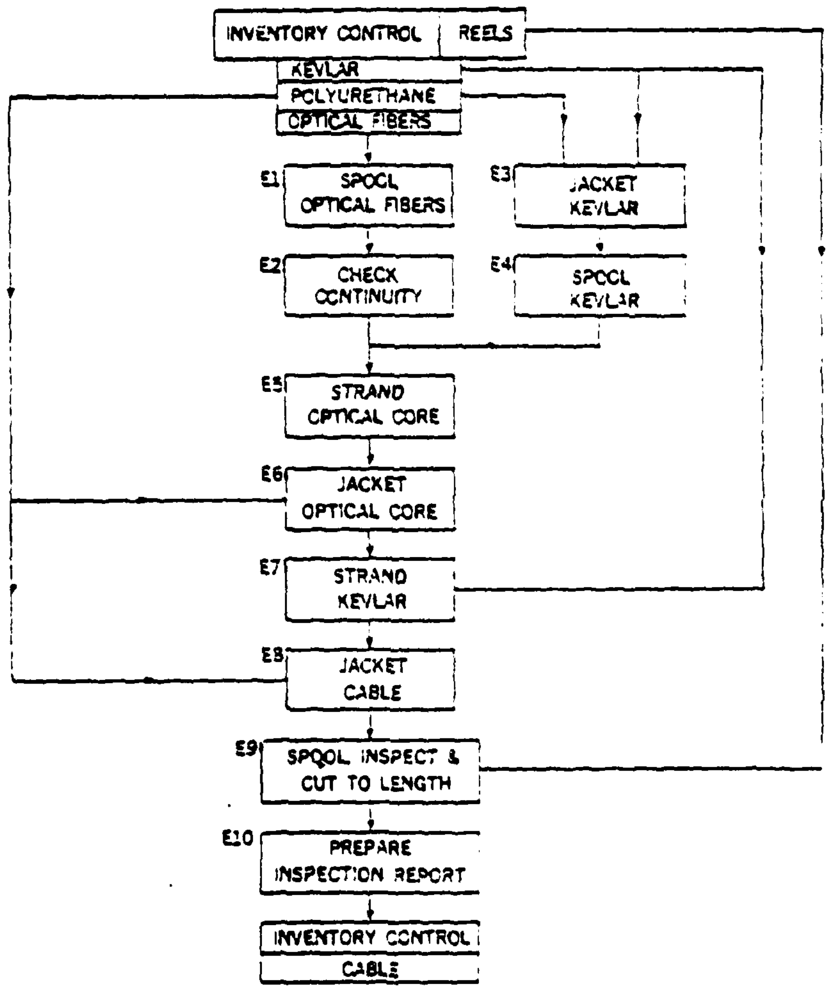

Figure 2. Cable Fabrication Flow Chart.

silicon detector. The LED and detector will be properly mounted for automatic axial alignment and quick operation to minimize the time required to examine each fiber for light transmission.

To complete this unit, minor modifications to existing equipment is all that will be required to optimize this test station.

1.2.1.3 Kevlar® Jacketing Station

The purpose of this station (Figure 2, Operation E3) is to overcoat a Kevlar® 49-380 denier yarn with a polyurethane jacket which will be used as the central core for the optical bundle. The extruder to be used is a 1 inch unit with the capacity of pressure extruding the polyurethane jacket at a current rate of 76 m/min.

This unit is an existing production station. An automatic diameter controlling process unit was installed. This unit detects the diameter of the core element being extruded and regulates the extruder rpm to provide a constant diameter over the length of a standard production run.

1.2.1.4 Respooling Station for Polyurethane Jacket Kevlar ®

This operation will be completed using the fiber rewind station equipment outlined in paragraph 1.2.1.1. The capacity of this unit is ample to complete both fiber rewind and respooling operations (Figure 2, Operation E4).

1.2.1.5 Optical Core Stranding Station

The purpose of this station (Figure 2, Operation E5) is to strand the six optical fibers helically around the Kevlar ® center core member. To do this operation, a high speed single twist closing unit equipped with a seven bay neutralizing unit will be used.

This unit is functional at 1800 m/h with excellent results and no further equipment problems.

1.2.1.6 Optical Core Jacketing Station

This station is to be used to extrude the polyurethane jacket over the optical bundle. The extruder is a 1 1/2 inch extrusion line capable of extruding the first jacket at 68 m/min, well over the required MM&T rate of 20 m/min.

The new payoff unit was installed and functions properly. This unit will handle the larger capacity spools needed to run long lengths (4 km) of cable.

1.2.1.7 Kevlar® Stranding Station

The purpose of this station (Figure 2, Operation E7) is to strand 18 Kevlar® strength members around the jacketed optical core. The modified yarn serving machine has been received, installed, and currently operational at 800 m/h.

1.2.1.8 Final Jacketing Station

The 2 inch extrusion line (Figure 2, Operation E8) will be used to extrude the final jacket on the ruggedized cable. The extrusion line was used to extrude the final jacket at 42 m/min on the polyurethane evaluation samples in Phase III. This rate is double that required (0.8 h/km) on the MM&T program. A new GENCA crosshead was installed to facilitate the extrusion of larger optical cables.

1.2.1.9 Final Cable Respooling Station

At this station (Figure 2, Operation E9) the cable will be spooled onto the shipping reel, inspected for visual defects, and cut into 1 km ±5 m lengths. This unit is fully operational at speeds well in excess of the program requirements.

2.0 FIBER AND CABLE TEST STATIONS

In the fourth quarter, the major emphasis was on the final assembly and characterization of the evaluation stations. An initial time study was conducted at each station.

The modifications required to meet the contract objectives were made to the stations and tests were conducted to determine the test stations characteristics.

2.1 Fiber End Preparation Station

This station will be used to remove the polyurethane jacket from both ends of the cable, strip the fiber buffer layer, cleave the fiber ends, and apply the mode stripping compound. The initial time study indicates that speeds in excess of program requirements can currently be achieved.

2.2 Pulse Dispersion Station

The second avalanche photodiode was added to the dispersion station of Figure 3. This addition facilitates continuous monitoring of the input pulse condition during a measurement without disturbing the fiber under test. Of a number of detectors which were tested for similarity of time response

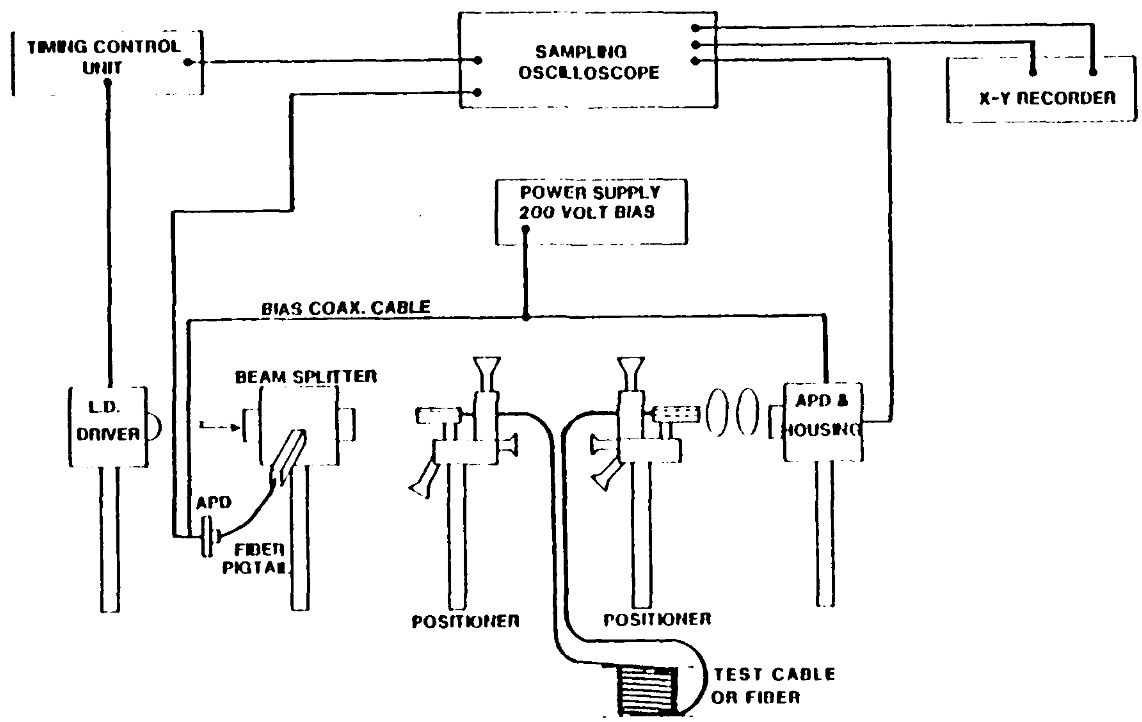

Figure 3. Dispersion Test Measurement Station.

referenced to the output detector, a C30921E cane-coupled APD was selected.

To demonstrate the capability of the monitor APD to track the input pulse, tests were conducted comparing the beam splitter pulse with the pulse from a one meter length of graded index fiber at various drive levels. The results, show excellent tracking near the usual drive condition of V threshold +1 V. At lower and higher drive levels, the agreement is much less reproducible due to instabilities in the laser output.

A total of nine dispersion measurements were performed on a 1200 m graded index fiber to gage reproducibility. The results shown in Table 1 indicate acceptable variations of ±7 per cent. The initial time study indicates that speeds in excess of program requirements can currently be achieved.

2.3 NA Test Station

The NA test station shown in Figure 4 has a motorized traverse which moves at speeds in excess of 15 mm/s. The signal output is maximized, the fiber is moved away from the detector to reach

Table 1. Dispersion Reproducibility.

MEASUREMENT NUMBER	PULSE DISPERSION ns/km (0.9µm, FWHM)
1	.43
2	.38
3	.40
4	.48
5	.42
6	.39
7	.44
8	.45
9	.40

$\bar{x}$ = .42 ns/km

s = .03 ns/km

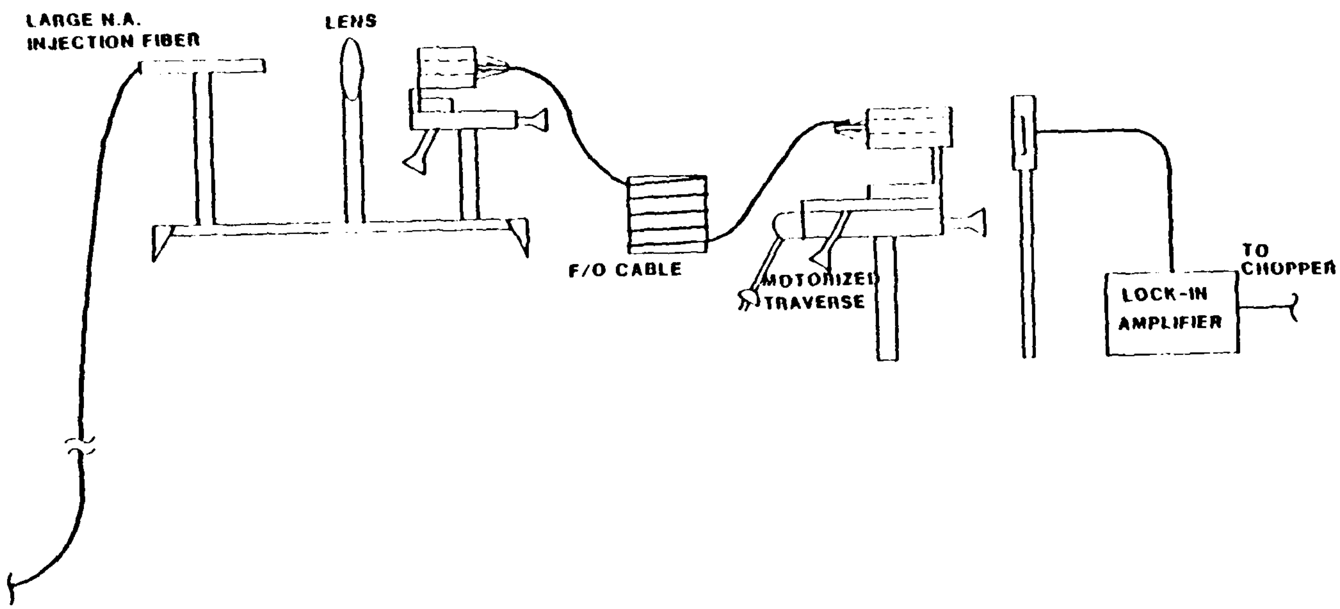

Figure 4. 90% Power NA Measurement Station.

the 90% signal level, the distance is recorded, and the 90% NA value is calculated. Tests were conducted to determine the reproducibility of the station. The data, shown in Table 2 indicates a variation of ±0.4% worst case for the same injection conditions on a short length test. The long length measurement variation was ±1.5% when new detection ends were made with each measurement. The initial time study indicated that 90% of required rate was achieved. With additional operator training and experience the speed will be greatly improved on this station.

2.4 Attenuation Measurement Station

The attenuation station of Figure 5 was assembled. The station utilizes Rofin germanium APD detectors to monitor both the input and output power over the wavelength region of interest (0.82 to 1.20 μm).

A number of tests have been initiated to determine measurement reproducibility and monitor tracking ability. The data in Figure 6 and Table 3 and 4 indicates excellent reliability in the measurement results. The initial time study on this

Table 2. 90% Power NA Repeatability.

A. SHORT LENGTH - REPEATED WITH SAME INJECTION CONDITIONS

1. .2125
2. .2131
3. .2127
4. .2121
5. .2113

$\bar{x}$ = .212

σ = .001

SAMPLE = 5 M OF FIBER (M-3) GRADED INDEX

B. FULL LENGTH - NEW DETECTION ENDS

1. .2026
2. .2028
3. .1997
4. .2072
5. .2048

$\bar{x}$ = .2034 = .203

σ = .0028 = .003

SAMPLE = 1200M OF FIBER (M-3) GRADED INDEX

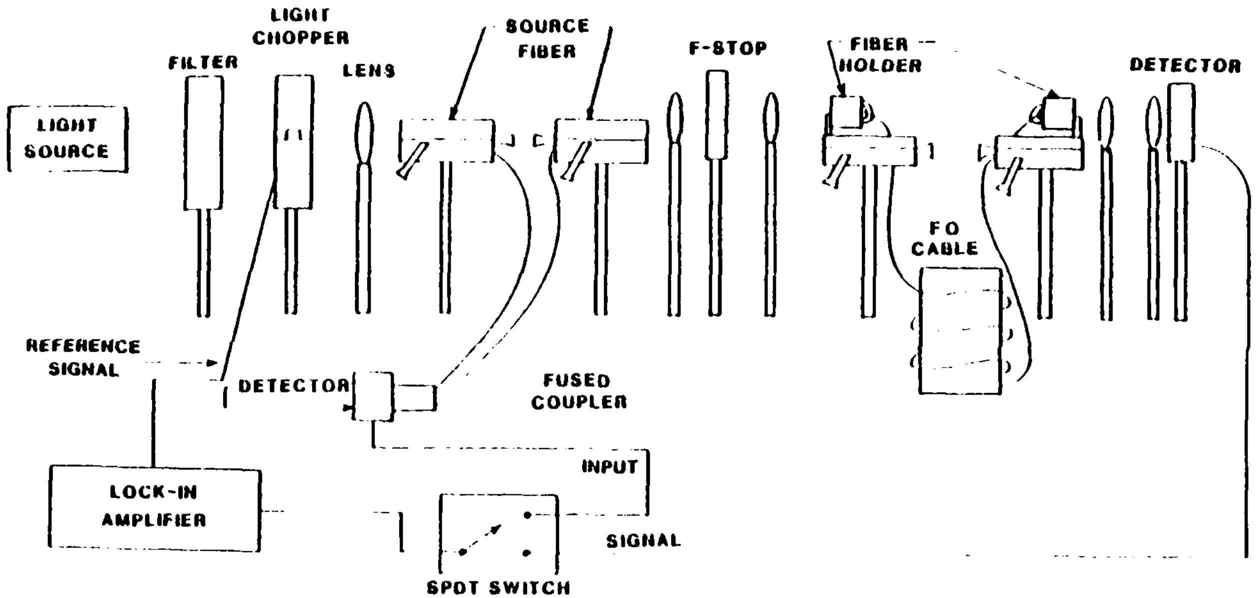

Figure 5. Attenuation Measurement Station.

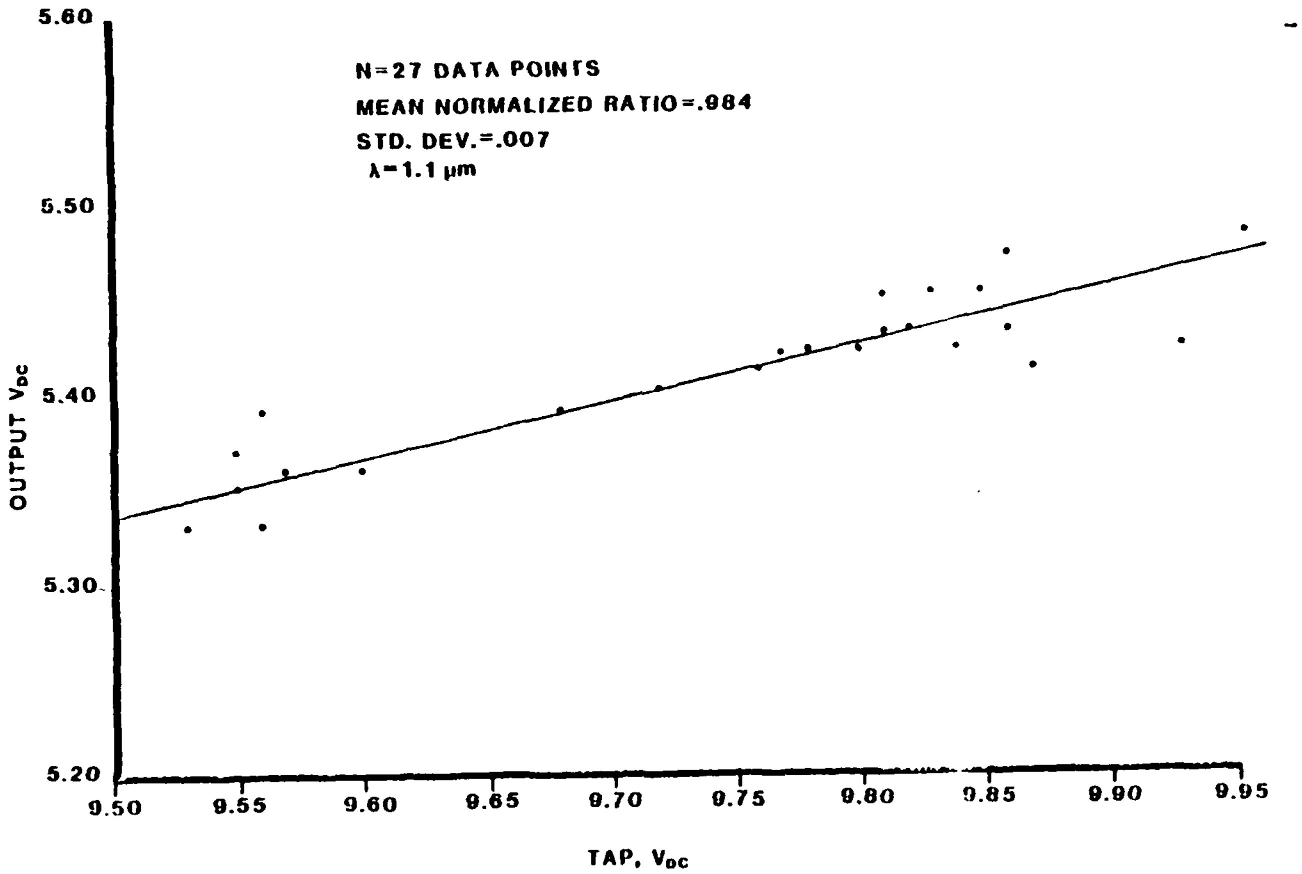

Figure 6. Monitoring Coupler Tracking Test.

Table 3. Production Attenuation Reproducibility.

MEASUREMENT NUMBER	RAW ATTENUATION dB/KM	CORRECTED ATTENUATION dB/KM
1	3.92	3.80
2	4.06	4.01
3	3.79	3.84
4	3.83	3.79
5	3.76	3.71
6	3.78	3.81
7	3.79	3.79
$\bar{x}$	3.85	3.82
σ	0.11	.09

SAMPLE M-3 FIBER

Table 4. Engineering Attenuation Reproducibility.

	WAVE LENGTH (μm)	.82				.85	1.06	1.10	1.20
	INJECTION (NA)	.089	.124	.176	.243	.089	.089	.089	.089
MEASUREMENT NUMBER:	A. RAW ATTENUATION dB/km								
1		3.62	3.74	3.87	3.94	3.15	1.44	1.30	1.09
2		3.93	4.00	4.11	4.12	3.42	1.48	1.35	1.04
3		3.68	3.80	3.98	4.34	3.21	1.50	1.32	1.10
4		3.78	3.90	4.21	4.47	3.31	1.50	1.36	1.13
5		3.70	3.78	4.16	4.37	3.22	1.43	1.25	1.01
6		4.00	4.12	4.36	4.64	3.51	1.71	1.54	1.28
$\bar{x}$		3.79	3.89	4.12	4.31	3.30	1.51	1.35	1.11
σ		0.15	0.15	0.17	0.25	0.14	0.10	0.10	0.10
MEASUREMENT NUMBER:	B. CORRECTED ATTENUATION dB/km								
1		3.67	3.79	3.92	3.99	3.27	1.53	1.36	1.12
2		3.94	4.01	4.12	4.13	3.35	1.53	1.36	1.04
3		3.73	3.85	4.03	4.39	3.29	1.59	1.38	1.17
4		3.84	3.96	4.27	4.53	3.36	1.55	1.39	1.19
5		3.70	3.78	4.16	4.37	3.23	1.44	1.28	1.03
6		3.96	4.08	4.32	4.60	3.44	1.63	1.48	1.22
$\bar{x}$		3.81	3.91	4.14	4.34	3.32	1.55	1.38	1.13
σ		0.13	0.12	0.15	0.23	0.08	0.06	0.06	0.08

[illegible] SAMPLE FIBER M-3

station also indicates rates in excess of program requirements. The time study data in Table 5 indicates that all stations can exceed production rates with trained operators. The time to run some steps will be reduced when a fiber stripping tool is used and further reduced as equipment is automated. Additional time studies will be conducted during the confirmatory sample phase.

Table 5. Initial Time Study Evaluation

	Measurement Station	Production Rates(hrs/km) Required	Proposed	Actual
F01	Prepare Fiber & Cable Ends	1.000	0.833	0.357
F02	Dispersion	1.000	0.918	0.660
F03	90% Power NA	1.000	0.744	0.994
F04	Attenuation	1.000	0.918	0.902

3.0 FLOW CHART OF MANUFACTURING PROCESS

Figures 2 and 7 show the flow of materials and product through the proposed pilot line production facility. Each station is identified with a letter/number code.

Plans are to produce cables in lengths of 4 km, thus reducing setup time at each station considerably. The expected result of the above is to increase efficiency so that the overall production yield will be 87%. This yield was evaluated after the final optimized engineering samples were constructed in a 3.6 km continuous length. The results show a 98% yield, well above production goals.

Table 5 lists all operations with the expected production rate at each work station. (Major work stations have been discussed in paragraph 1.2.) At this time in the program there is no obvious reason to believe that the proposed production rates cannot be met or exceeded.

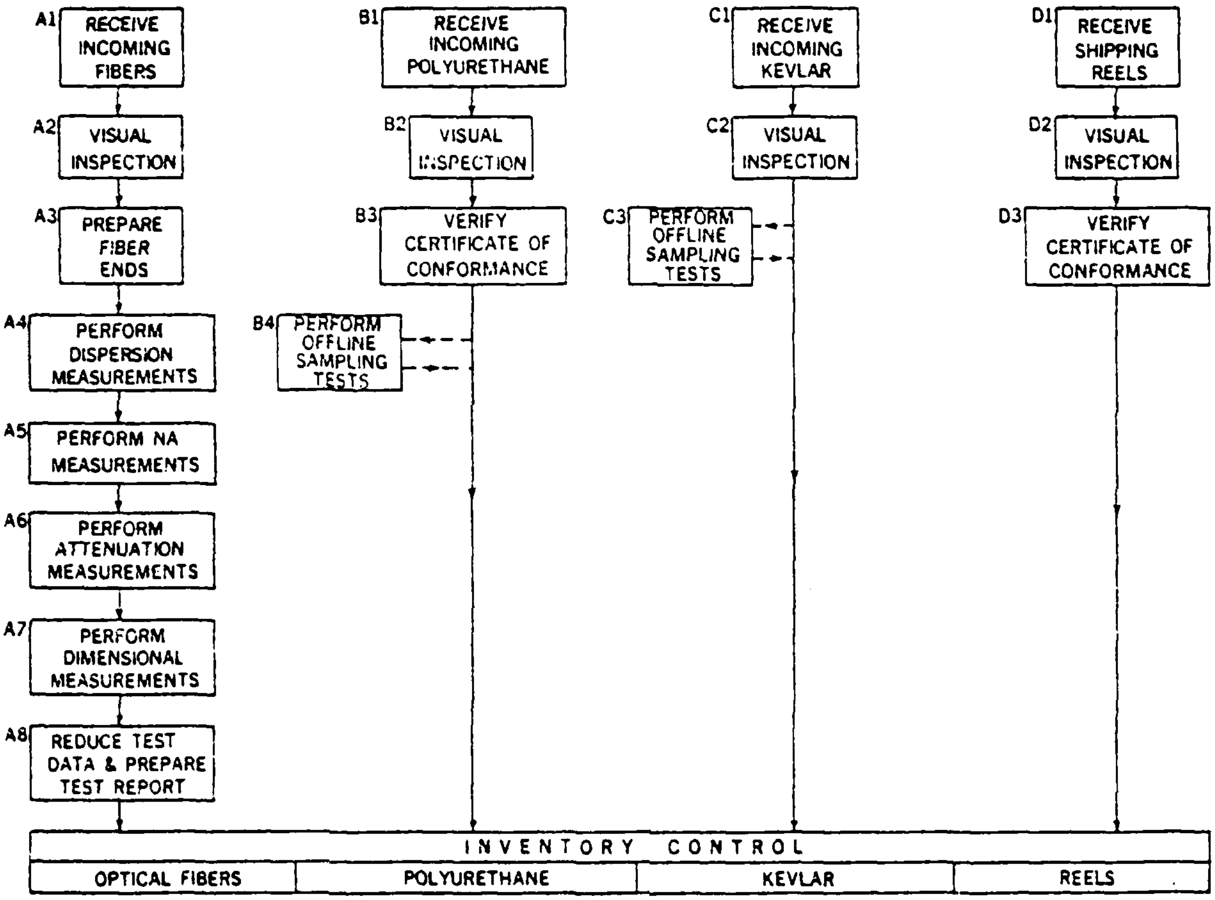

Figure 7. Incoming Inspection and Quality Control Flow Chart.

Table 5. Production Rate by Operation.

Operation	Operation Description	Set-up Time hrs/km	Run Time hrs/km	Total Time hrs/km Cable
A01	Receive Incoming Fibers	-	-	-
A02	Visual Inspection	0.020	-	0.184
A03	Prepare Fiber Ends	0.020	-	0.184
A04	Perform Dispersion Measurement	0.050	-	0.459
A05	Perform NA Measurement	0.050	-	0.459
A06	Perform Loss Measurement	0.050	-	0.459
A07	Perform Dimensional Measurement	0.050	-	0.459
A08	Reduce Test Data and Prepare Test Report	0.080	-	0.736
B01	Receive Incoming Polyurethane	-	-	-
B02	Visual Inspection	0.020	-	0.026
B03	Verify Certificate of Conformance	0.010	-	0.013
B04	Offline Sampling Tests	-	-	-
C01	Receive Incoming KEVLAR	-	-	-
C02	Visual Inspection	0.020	-	0.026
C03	Offline Sampling Tests	-	-	-
D01	Receive Shipping Reels	-	-	-
D02	Visual Inspection	0.050	-	0.056
D03	Verify Certificate of Conformance	0.050	-	0.056
E01	Spool Optical Fibers	0.030	0.090	0.327
E02	Check Continuity	0.050	-	0.344
E03	Jacket KEVLAR	0.130	0.370	0.574
E04	Spool KEVLAR	0.030	0.090	0.138
E05	Strand Optical Core	0.060	0.810	1.000
E06	Jacket Optical Core	0.260	0.540	0.918
E07	Strand KEVLAR	0.200	0.410	0.700
E08	Jacket Cable	0.230	0.157	0.918
E09	Spool, Inspect & Cut to Length	0.170	0.630	0.918
E10	Prepare Inspection Report	0.500	-	0.556
F01	Prepare Fiber & Cable Ends	0.750	-	0.833
F02	Perform Dispersion Measurement	0.800	-	0.918
F03	Perform NA Measurement	0.670	-	0.744
F04	Perform Loss Measurement	0.300	-	0.918
F05	Perform Dimensional Measurement	0.300	-	0.913
F06	Prepare Cable Ends for Shipping	0.130	-	0.202
F07	Reduce Test Data and Prepare Test Report	0.560	-	0.734
F08	Offline Sampling Tests	-	-	-
	Total Production Time			15.277

4.0 CONCLUSIONS

The data from the final engineering samples has resulted in the 0.89 mm ±0.05 mm Hytrel® 7246 fibers being selected because of best overall performance in the cable.

The 7.6 cm lay length was chosen because of an increased cable production rate over shorter lay lengths, without any penalty in performance.

Tubing extrusion was selected over pressure extrusion for the following reasons:

a. Higher production speed
b. Better concentricity
c. Greater production yield
d. Equal optical and mechanical performance
e. Less material scrap

Based on the results discussed in Section 1.1.2, Roylar® E-80 will be used in the confirmatory sample phase.

No problems have been identified in the equipment or measuring station design which will adversely affect the delivery schedules or performance milestones. All milestones have been achieved on or ahead of schedule.

5.0 PROGRAM FOR NEXT INTERVAL

Milestone achievements for the next quarterly interval are listed below:

a. Fabricate confirmatory samples

b. Initiate testing of confirmatory samples

c. Increase Kevlar® serving line speed to production rate

d. Evaluate induced cabling loss to achieve 0.25 dB/km

e. Evaluate cable yield to achieve 75%

f. Run additional time studies on measurement stations

6.0 PUBLICATION AND REPORTS

There have been no publications, conferences and/or talks made during the period on or associated with the research, study, or development under contract.

7.0 IDENTIFICATION OF PERSONNEL

Table 6 is a list of the names of personnel working on the program who are considered professional and skilled technical personnel. The task performed and the manhours of work performed by each during the interval of the report are given.

Table 6. Personnel Working on the MM&T Program.

Name	Task	Manhours Expended
R. Coon	Program Management	154
J. Smith	Cable Production Management	50
R. Thompson	Technical and Administrative	35
R. Kopstein	Project Engineer and Cable Development	358
S. Mahurin	Measurements Supervision and Project Engineering	110
H. Heinzer	Measurements Engineering	15

R. Coon has been assigned as Program Manager for the program. R. Hoss has overall responsibility for the program as Program Director. Mr. Coon's resume is included.

ITT ELECTRO-OPTICAL PRODUCTS DIVISION REVISION DATE 5/19/80

BIOGRAPHICAL INFORMATION

NAME: Robert L. Coon

POSITION: Program Manager - Fiber Optics

EDUCATION:

Mr. Coon was awarded a BS degree in physics from Michigan State University in 1956. He received an MS degree in physics from Stevens Institute of Technology in 1962.

EXPERIENCE:

Mr. Coon joined ITT Electro-Optical Products Division in March 1980. As Program Manager of the Fiber Optics Laboratory, his responsibilities include providing program direction and program coordination and the preparation of schedule and cost plans to meet the requirements of major fiber optic programs within EOPD.

Prior to joining ITT, Mr. Coon was Program Manager in the Military Systems Division of International Laser Systems, Inc. (ILS). In this position he was responsible for all aspects of major laser programs including proposal preparation, negotiation of contracts, program planning, allocation of resources, coordination with the customer, management of all aspects of data preparation, and hardware construction and delivery. Mr. Coon's duties at ILS included management of the Nd:YAG Laser Transmitter Program, a major project involving development and delivery of six advanced development lasers for integration into military hardware, and the TADS Laser Program, which involved development of the laser rangefinder/designator for the Advanced Attack Helicopter Program.

From 1975 to 1977 Mr. Coon managed a nine-man organization which controlled U.S. assistance to the Republic of Korea in the acquisition of military equipment.

He represented the U.S. Army in a Department of Defense organization which conducted countermeasures testing of laser guided weapons systems from 1973 to 1975. His responsibilities in this position included the development of test plans, testing, and test reports. The system of testing he instituted resulted in more effective systems evaluation and rapid incorporation of counter-countermeasures. He evaluated planned coding schemes for laser guided weapons designed to prevent decoying the systems, and he prepared a study which resulted in the Department of Defense revising coding techniques to a more reliable and cost effective coding system for all services.

ADMINISTRATIVE

Mr. Coon's experience includes management of a 12-man group whose duties involved development of three major systems: the HELLFIRE missile system, the Ground Laser Locator Designator, and the Airborne Laser Locator Designator. From 1969 to 1971 he managed an eight-man group responsible for the fielding and support of the Land Combat Support System.

APPENDIX A

PHASE I AND II OPTIMIZATION RESULTS

A1.0 NARRATIVE AND DATA

The following information covers a physical description of the device, performance, effects of processes, and measurement techniques used on this program.

A1.1 Device

The following paragraphs define the methods used to optimize the ruggedized tactical fiber optic cable, manufacturing processes, and measurement techniques.

A1.1.1 Ruggedized Cable Design

The purpose of this program is to establish an automated production process for a ruggedized tactical fiber optic cable. Figure 1 shows the general cable configuration to be optimized on the program.

The light transmitting elements of the optical cable are the optical fibers consisting of a glass core and glass cladding. To preserve the mechanical strength of the glass fibers, they are coated with plastic buffers, the buffer being a solid plastic coating surrounding the optical fiber.

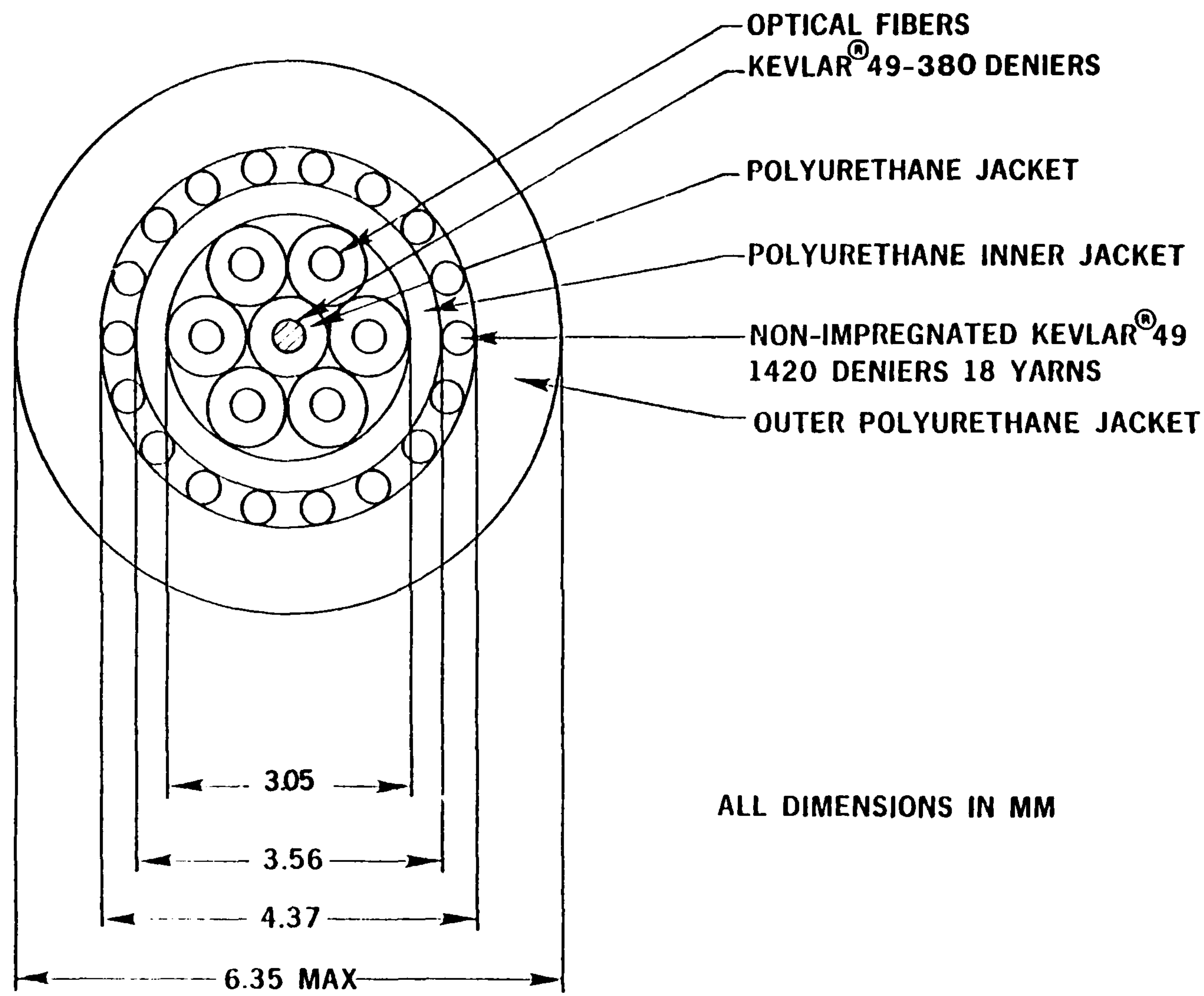

Figure A.1 Basic MM&T Cable Design.

The graded-index optical fibers are to meet the following specifications at 0.82 μm wavelength after proof loading at 100,000 psi:

a. Fiber core — ≥ 50 μm

b. Fiber od — 125 μm ±6 μm

c. Attenuation — ≤ 5.0 dB/km

d. Dispersion — ≤ 2.0 ns/km

e. Numerical aperture (90% power) — ≥ 0.20

A1.1.1.1 Primary Buffer

A room temperature vulcanizing (RTV) silicone protective coating, Dow Corning Sylguard® 184, is applied by dip coating to a finished diameter of 300 μm immediately after drawing. This protective coating guards the fibers from any initial handling or foreign substances that may damage or reduce the quality of the product and is compatible with the buffering materials.

A 1.1.1.2 Secondary Buffer

All fibers have a Hytrel® 7246 buffer layer for additional protection. This layer is extruded to a finished diameter of 0.5 mm. An additional layer is extruded to 1.0 mm to provide the optimum mechanical and environmental performance. The "1" extruder is used for this operation.

Hytrel ® has a very low expansion/contraction coefficient, thereby improving the high/low temperature performance.

A1.1.1.3 Center Filler

The center filler shall be a Kevlar ® 49 (380 denier) coated with polyurethane (Roylar ® E-80) to a diameter of 1.0 mm. The center filler provides a cushioning to improve impact resistance.

A1.1.1.4 Polyurethane Inner Jacket

The polyurethane inner jacket is extruded after the cabling operation. The polyurethane used is a polyether based compound. It is chosen because of its extreme toughness, abrasion resistance, low temperature flexibility, resistance to hydrolysis, fungus resistance, and excellent stability to atmospheric conditions. This jacket supplies support for the fiber making up the cable core and provides a buffer layer between the fiber and Kevlar ® reducing abrasion.

A1.1.1.5 Kevlar ® Strength Member

Kevlar ® 49 has been chosen as the strength member for this application because of its strength versus weight and durability. A total of 18 yarns (1420 denier) is applied helically with a 4.0 in lay length. The lay length was selected to be greater than that of the fibers to ensure that the Kevlar® takes the tensile load. The strength member will provide 400 lb tensile strength at 1% elongation. One percent elongation is the 100 kpsi fiber proof test point.

A1.1.1.6 Polyurethane Outer Jacket

The outer jacket material is identical to the inner jacket specified in Section A1.1.1.4.

A1.1.2 Optimization Process

The basic fiber optic cable will be optimized in four specific areas or phases. The three sets of engineering samples will be selected from this four-phase optimization process.

A1.1.2.1 Fiber Buffer Optimization (Phase I)

Three buffered fiber diameters of 0.94 mm, 1.02 mm, and 1.14 mm with Hytrel® 7246 were evaluated. Also, fibers were evaluated at 1.0 mm with Hytrel® 4056, Hytrel® 5556, and polyurethane Roylar® E-80. This phase is completed and cable samples from this phase were shipped as the first set of engineering samples.

A1.1.2.2 Lay Length Evaluation (Phase II)

Cables were evaluated with fiber lay lengths of 2.0 in, 2.5 in, and 3.0 in. It is felt that lay lengths shorter than 2.0 in would cause induced microbending losses and lay lengths greater than 3.0 in would cause additional tensile load stresses along with high bending stresses.

A1.1.2.3 Pressure Versus Tubing Inner Jacket

The inner jacket was optimized by evaluating pressure versus tubing extrusion process.

A1.1.2.4 Outer Jacket

The polyurethane was optimized by evaluating four different manufacturers of polyether grade urethanes.

A1.1.3 Purpose of Phase I Optimization

Phase I of the MM&T program was designed to evaluate the effects of buffered fiber diameter and material type and hardness on the cable performance as follows:

a. Buffered fiber diameter, Hytrel® 7246 (0.94 mm, 1.02 mm, 1.14 mm)

b. Hytrel® hardness effects (4056, 5556, 7246)

c. Material comparison (Hytrel® versus polyurethane)

A1.1.4 Purpose of Phase II Optimization

Phase II of the MM&T program optimized the fiber lay length (2.0 in, 2.5 in, 3.0 in).

A1.1.4.1 Phase II Optimization

This optimization evaluated the cabled fiber lay length. Three cables have been constructed using the high speed strander at 50% of production rate under this phase II program following the basic cable design of Figure 1 with 1.02 mm Hytrel® 7246 fibers and the following variations:

a. Design no 1 - 2.0 in lay length

b. Design no 2 - 2.5 in lay length

c. Design no 3 - 3.0 in lay length

A1.1.4.2 Manufacturing Problems

All cables were constructed without any problems; therefore, the lay length of the cabled optical fibers does not affect the manufacturing difficulty but does have a direct relationship to the manufacturing rate. It was decided at the onset of this phase to evaluate tubing versus pressure extrusion of the cable core in the event that the cable could not pass the impact testing requirement. Tubing extrusion was selected over pressure extrusion without further engineering samples because the fibers already withstand the impact test and pressure extrusion would only improve impact performance but would have the following disadvantages:

a. Lower production speed

b. Poor concentricity

c. Lower production yield

d. Equal optical and mechanical performance

e. More material scrap

Construction of engineering samples to evaluate pressure versus tubing performance was not a requirement in the MM&T program.

A1.1.4.3 Phase II Conclusions and Recommendations

The data from the phase II samples (see Tables 2 and 3) was used to select the optimized lay length from the optical and mechanical results. All three cables had excellent optical results. One of the fibers was broken in the 2.0 in lay length cable because of stepper motor problems with the high speed strander. The motor was replaced and no further problems have developed.

Table A.2 Attenuation Data.

	Design No 1			Design No 2			Design No 3		
	2.0" Lay Length			2.5" Lay Length			3.0" Lay Length		
	Attenuation (dB/km)*			Attenuation (dB/km)*			Attenuation (dB/km)*		
Fiber Ident	Before	After	Δ	Before	After	Δ	Before	After	Δ
1. Red	4.20	4.16	-0.04	3.95	3.65	-0.30	4.12	4.15	+0.03
2. White	3.74	**	**	3.58	3.67	+0.09	3.52	4.01	+0.49
3. Blue	3.79	3.99	+0.20	3.87	3.83	-0.04	4.16	5.55	+1.39
4. White	3.76	4.31	+0.55	3.70	3.23	-0.47	3.43	3.60	+0.17
5. White	3.81	3.56	-0.25	3.89	3.63	-0.26	3.48	3.55	+0.07
6. White	3.71	3.86	+0.15	3.54	3.31	-0.23	3.96	3.32	-0.64
Avg.	3.85	3.98	+0.13	Avg. 3.76	3.55	-0.21	Avg. 3.78	4.03	+0.25

*Attenuation measured at 0.82 μm wavelength and 0.089 injection NA

**Fiber broke on high speed strander when bearings of the stepper motor failed.

Table A.3 Mechanical Testing.*

	Design No 1 2" Lay Length	Design No 2 2.5" Lay Length	Design No 3 3.0" Lay Length
Impact Resistance			
Total fibers	36	36	36
Failures	1	0	0
Percent surviving fibers	97.2	100.0	100.0
Twist Test			
Total fibers	18	18	18
Failures	0	0	0
Percent surviving fibers	100.0	100.0	100.0
Bend Test			
Total fibers	18	18	18
Failures	0	0	0
Percent surviving fibers	100.0	100.0	100.0
Tensile Load Test			
Total fibers	6	6	6
Failures	0	0	0
Percent surviving fibers	100.0	100.0	100.0

*All testing was conducted at room temperature

The mechanical testing data showed excellent results also with only one fiber failure on the 2.0 in lay length cable during the room temperature inpact testing.

A 3.0 in lay length was selected for Phase III (polyurethane evaluation) based on the test results and because an increase in stranding rate can be realized over the shorter lay lengths. Stranding speed is a direct function of lay length. Further information was included in the test report for the second engineering samples.

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